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Admiral of the Fleet The Lord Hill-Norton G.C.B.

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28th April, 1986

The Rt. Hon. Margaret Thatcher B.Sc., MA, FRS, MP,
10 Downing Street,
London,
SW1.

Dear Prime Minister,

Hull Forms for Warships

Formal proposals were made to the Ministry of Defence about three years ago by Thornycroft Giles and Associates Ltd., for a broad beamed warship design of frigate. TGA claimed that this radical departure from the conventional long, thin hull form, traditional in the Royal Navy since the beginning of the century, would be substantially cheaper to build and maintain, and would offer significant operational advantage in nearly all important military respects.

These claims were examined in 1983 by the Defence Scientific Advisory Council, which rejected them, concluding "..... from the evidence available to us, we conclude the S.90 (the TGA design) would not be an effective warship."

An unofficial committee, of which I am Chairman, has looked into this controversy, in as much detail as our resources permitted, and our Report is attached. We have no doubt that the rejection of the merits of the short fat ship by the DSAC, and hence their conclusion, was unsound. Indeed we found the relevant document which formed the basis for their consideration of the matter to be seriously flawed.

We strongly recommend that our work should be examined, as a matter of urgency, by an independent committee, outside the Government service, of sufficient weight to reach authoritative conclusions. This matter is of the highest importance to the operational capability of the Royal Navy, and thus not only to your Defence Policy as a whole, but much industrial policy (including exports) as well. It is for these reasons that I am submitting the report to you personally.

X No other copies of the report have yet been distributed, though ample are available for the Ministries concerned at the appropriate time. When this arrives copies will also be released to several Embassies, certain individuals who are directly or indirectly concerned, to Members of both Houses of Parliament and to the media. My Committee colleagues and I are under some pressure from several Defence correspondents to set a date for a Press Conference at which our Report can be discussed. I have it in mind to propose a date about 15th May, unless for any reason you would prefer me to defer it.

Yours sincerely,

Hill-Norton.

10 DOWNING STREET

PRIME MINISTER

Despite Lord Hill Norton's last paragraph, I think that we will have to send this to MOD for advice.

He calls in his report for a judicial inquiry to adjudicate on the short fat ships controversy.

N.L.W.

(N.L. Wicks)

28 April 1986

Could we ask Lord HN if we could discuss the report with M.O.D.

I don't think a judge would be right for arbitrating — I can't think of names other than ex-naval men

Hull Forms for Warships

The Hill-Norton Committee Report, 1986

HULL FORMS FOR WARSHIPS

The 'long/thin' vs 'short/fat' controversy

The Hill-Norton Committee Report, 1986

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Summary

The conventional design of destroyers and frigates is based upon a long/thin hull, developed since the beginning of this century to optimise speed and fuel economy.

A radical alternative design concept has been proposed based upon a short/fat hull form which, it is claimed, would be much cheaper to build and would present several other substantial advantages, with no operational penalties.

It is high time that this controversy was resolved, in the interests of the operational capability of the Royal Navy, with less important but substantial effects on the warship building industries and, probably, exports.

An unofficial committee, whose report this is, was established in April 1985 to look at the whole problem. The most important findings are:

a. The claims of the proposers of the short/fat concept (Thornycroft Giles and Associates Ltd.) were examined by the Defence Scientific Advisory Council (DSAC), in 1983. We find that some statements in the paper prepared by its Hull Committee, and on which the deliberations were based, were wrong in fact, and that in others the opinions expressed were not well founded.

b. We therefore conclude that the rejection by the DSAC of the claims by TGA was unsoundly based.

c. We believe that, certainly for ships up to destroyer size, the short/fat hull form offers enough advantages in the important elements of construction time, habitability, between-deck and weather-deck layout, stability and sea-keeping, and weapon-siting, to merit much more serious consideration that it has so far been accorded.

d. We find that the short/fat hull form may offer a significant increase in top speed over the maximum which can be realised in a long/thin hull of similar size. If this is confirmed it is a most important military advantage.

e. If the 25% saving in the unit costs suggested by Frederikshavn Vaerft can be confirmed, a wide degree of flexibility is at once offered to the Royal Navy with the choice of a major increase in military capability or a corresponding reduction in the procurement budget.

Recommendation

We recommend that an Official Committee of Enquiry be established, under the Chairmanship of a learned Judge or Queen's Counsel, with independent members expert in the relevant fields, to validate or reject our detailed conclusions and report the results urgently to the Prime Minister.

Introduction

1. Conventional warship design for frigates and destroyers is based upon the long thin/hull developed since the beginning of this century, for sound technical and operational reasons, of which the most important were speed and fuel economy. Such hulls require high grade steel (for strength) and are difficult to fabricate, which makes their cost high; while, as a result of the inconvenient shape of the spaces above and between decks, it is awkwardly complex and expensive to fit in the main and auxiliary machinery, the weapons suite, and the crew accommodation. The conventional design is intolerant of topweight, which can give rise to problems of stability.

2. It is claimed that a radical alternative, in the shape of a short/fat hull form, would provide very substantial advantages in building and maintenance costs, in construction time, and in simplicity of layout, with no operational penalties. Indeed, it is further claimed that such vessels would be more stable, with better sea-keeping and manoeuvring performance, more commodious between-decks space and thus better accommodation, and that they would be able to carry a greater weapon outfit.

3. This controversy, conducted mainly at the professional/technical level, has rumbled on for many years. It emerged into the public domain comparatively recently, in about 1982, and remains a bone of contention, with the proponents of each school of thought fighting their corners with increasing intemperance. The satisfactory resolution of this disagreement is a matter of the highest importance for the operational capability of the Royal Navy, and thus for defence policy as a whole, with important down-stream effects on warship building and connected industries, particularly in a period of very heavy pressure to contain public expenditure. It is clear enough that a serious attempt to set out the relevant matters of fact, and to form a judgement upon them, is required, indeed overdue.

Formation and Status of the Committee

4. These issues were discussed in a general way at a meeting in London on 27 March 1985. It was agreed that the official comparison in 1983 between the short/fat hull form and the conventional long/thin concept, for destroyer and frigate applications, may have been prejudiced in favour of the latter and, hence, less than fully objective. Some of the theoretical objections raised before the Defence Scientific Advisory Council (DSAC) to the short/fat alternative[1] were held to be wrong in fact, and there seemed to be other substantial grounds for questioning the validity of the Ministry of Defence (MOD) preference for the conventional form.

[1] Throughout this report we use the name Sirius for this concept; where reference is made to the S.90 this means a Sirius hull of 90 metres length (80 metres on the waterline)

5. It was accordingly agreed to establish an independent, unofficial committee to examine and report on the relative merits of the two hull forms as the basis for the design of warships up to destroyer size. To the extent possible, and in a time-scale measured in months, account was to be taken of operational performance, construction methods, time scale and design, and through-life costs, all on a comparative basis.

6. It was recognised that with no access to classified information, no qualified staff or support, and no ability to demand written or oral evidence, the conclusions of the Committee were bound to carry no more weight than that which flows from their individual and collective knowledge and experience.

7. It was agreed that the Committee should consist of:
Admiral of the Fleet Lord Hill-Norton (Chairman)
Lord Strathcona and Mount Royal
Professor R.V. Jones
Doctor Richard L. Garwin
and a note on their qualifications is at Annex A. Sir Terence Conran agreed to act as an adviser on habitability and accommodation design, and Mr Charles Hoste agreed to act as Secretary.

Point of Departure

8. We took, as the basis for our comparative examination, the criteria used by the Hull Committee of the DSAC to determine the effectiveness of a fighting ship:

a. The ability of the ship, as a vehicle, to meet the (staff) requirements for performance, sea-keeping and so on;

b. The ability of the ship, as a platform, to carry the required weapon systems in the required numbers, with the required operational performance;

c. The ability of the ship, as an integrated unit, to deploy effectively its own weapons and to withstand to the required limits, the effects of the enemy's weapons.

9. Our gloss upon these criteria was to seek a design approach, by comparing the alternatives before us, which will maximise military capability at a given ship-cost or, alternatively, to minimise cost for a given military capability. In this analysis, elements of the cost of achieving a prescribed military capability, such as fuel consumption, may be traded off against other costs such as those of construction, refit, maintenance, available operational sea-time, and so on.

Method of Work

10. The leading public proponents of the short/fat (Sirius) hull design for this warship application are Thornycroft Giles and Associates (TGA) supported by Frederikshavn Vaerft, Denmark (FV). Following a meeting of the DSAC on 10 March 1983, at which TGA's proposals were presented, the Hull Committee decided to submit to the Marine Technology Board its review of the design philosophy of the Sirius.

11. The Board endorsed the conclusions of the Hull Committee's paper on 23 June 1983. It quickly became clear to us that nearly all the points of disagreement about the two hull forms were included in that paper, and we decided to study each of those points in detail.

12. Our Committee met on 6 August 1985 to consider the Hull Committee's paper, having before us detailed comments upon it by Dr Garwin, Frederikshavn Vaerft, and TGA; together with a record of discussions which Dr Garwin and Professor Jones had held with Admiral Sir Lindsay Bryson and separately with Professor Bishop, the day before our meeting.

13. During this meeting we concluded that in the crucial matter of hydrodynamic lift the Hull Committee were wrong in fact, and in others that their opinions were not well founded, particularly as regards cost, power and stability including roll characteristics. Other points on which the opinions of the Hull Committee were open to question were hull resistance, weather-deck and accommodation space, and weight.

Detailed Argument

14. In view of this substantial challenge to the basis upon which the DSAC (and presumably the Ministry of Defence) rejected the design philosophy of the short/fat concept, we looked at those elements of any warship design which must be the most critical in assessing its likely success or failure, in varying degrees of detail. These are:

1. Construction and through-life costs
2. Design and construction time-scales
3. Main propulsion machinery
4. Displacement
5. Speed and endurance, including hull resistance
6. Stability, including roll, pitch and yaw in various sea states
7. Hull and radiated noise
8. Hull form as sonar platform, including towed arrays
9. Upper deck space for weapon layout
10. Damage survival, including shock resistance
11. Manning and habitability
12. Military capability

15. Our examination of these elements was, of course, constrained by the factors mentioned in paragraph 6 above, in particular our lack of hard information on such matters as through-life costings of certain frigates (and how they are calculated), the internal layout of ships such as the new Type 23 frigate, the correlation between 1/10 scale model sea trials and full scale results, and the like. We are, nevertheless, confident that the results of our examination which are set out in the following paragraphs, stand firmly on the basis of facts which are not in dispute.

Construction, Fitting Out and Through-life Costs

16. We have adopted the DSAC view that the major areas of cost may be divided into hull structure costs, machinery and outfit costs and weapons acquisition and installation costs. We have assumed in this report that the dock-side costs of the weapons suite are independent of hull form, but that the installation costs of both machinery and weapons will vary with hull form.

17. We have also accepted in a general way the DSAC breakdown of the proportions of the Unit Production Cost which may be attributed to those five major areas for a modern frigate. Plainly, a side by side comparison of costs, under those headings, of a conventional and a Sirius solution to the Type 23 Naval Staff Requirement would enable hard conclusions to be drawn, but we have been unable to make such a comparison because neither the expected costs, nor a breakdown of them, for the Type 23 design adopted by the MOD were available to us.

18. FV have made a comparison of the hull structure costs of a Sirius, and of the Leander class (being of similar displacement), at today's prices, built in Denmark. The results are:

		SIRIUS	£m	LEANDER
Materials (steel, alloy etc.)		0.324		0.680
Labour		3.500		8.100
Total	£m	3.824	£m	8.780

19. This substantial reduction may be accounted for partly by the use of cheaper material but primarily by the greater ease of its fabrication.

20. In Appendix 4 FV have calculated the cost of a conventional ship built in the UK, using the DSAC percentage breakdown and the Unit Production cost of £100m quoted by the MOD for the Type 23 when this was announced in October 1983. The paper compares these costs with those of an S90 design, also built in the UK, with the same weapons suite and to meet the same operational requirements. The results are:

		CONVENTIONAL SHIP	S90	%
Hull structure	£m	17.0	3.2	4
Machinery		25.0	18.3	25
Outfit		15.0	11.5	16
Electrical outfit		11.0	8.8	12
Weapons		32.0	32.0	43
	£m	100.0	£m 73.8	100

21. This represents a saving on UPC of £26.2m (or 26.2%) and can be accounted for by the factors to which we have referred above and partly by the much greater ease of fitting out, and thus greatly reduced labour costs, which are dealt with below and in the papers by Consep Ltd. at Appendices 3 and 6. If savings even approaching this magnitude can be confirmed, the effect on the frigate force of the Royal Navy would be highly significant.

22. Hull Structure

FV have demonstrated the greater structural economy achieved by increasing beam rather than length to accommodate greater displacement and volume. Within a given type of structure it is 30–40% more weight effective to increase beam, whereas the traditional approach to overcoming the penalty of increased structural weight is to use lighter but higher quality and therefore more expensive steel. This is borne out in the comparison of hull costs between S90 and Leander. The greater strength of the shorter and wider structure in longitudinal stress and its greater efficiency is also discussed by Dr Garwin and Professor Bishop.[1]

23. Outfit

The paper by Consep Ltd. and Conran Design Group Ltd.[2] highlights the advantages of the wider hull for accommodation, because much more of the available space (volume) can be put to use, which allows a more logical arrangement of mess decks, sanitation, galleys, store rooms and other "hotel" services to be provided within the hull. Crew accommodation can be concentrated more centrally in the vessel where motion at sea is less; this helps

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[1] Appendix 2

[2] Appendix 3

reduce crew fatigue. An additional advantage is the added flexibility of space usage to accommodate more readily modifications subsequent to building.

24. The length and complexity of each of the outfit systems and thus their cost, weight and vulnerability, will all be reduced. Similar advantages are cited by FV in the installation of ship systems and, in particular, weapons systems.

25. There is strong evidence that, for a given displacement, the volume of a shorter, wider structure is more easily outfitted due to the generally greater size of compartments, improved access and constructional "elbow room".

26. Weapons Installation

Consep Ltd. have described the substantial advantages of being less restricted in terms of volume and, particularly, distribution of topweight in the Sirius OPV III compared with traditional hulls.[3] For the first time in their experience they were able substantially to raise the height of very heavy sensors and equipment in order to take advantage of the initial stability available in the Sirius hull form. They cite this as a major overall benefit in the design, layout and installation of weapons, weapons systems, sensors and the provision of heating, chilled water and forced air ventilation to them.

27. Consep have also pointed out the greater ease of rendering the simple single superstructure assembly airtight for NBCD purposes, because of the much greater beam.

28. Machinery Installation

Due to the greater beam in the engine room area it is possible to fit a more concentrated and wider variety of machinery layouts than is possible with a long/thin ship. Thanks to the greater useful internal volume available it should not be necessary to position accommodation on decks above machinery spaces. This improves ease of installation and maintenance and, in particular, removal and replacement of major items during routine or unscheduled maintenance.

29. Through-life

We do not know the basis on which through-life costs for warships are currently calculated by the Navy Department, but cost analyses carried out by FV have shown that significant savings should be possible with this type of ship compared to the current production and operating costs of traditional designs.

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[3] Appendix 6

30. Major reasons for these cost savings are:–

(i) Heavier, and therefore cheaper, construction more adapted to current commercial techniques and equipment.
(ii) More convenient hull proportions for installation and replacement of accommodation, equipment, systems, weapons and machinery.
(iii) Heavier and less stressed commercial type structure requiring less frequent maintenance and repair and fewer maintenance manhours.
(iv) Less maintenance provides greater availability of each ship, thus increasing the annual utilisation of a given number of ships. This can be used either to increase the effectiveness of such a given number of ships, or their number can be reduced for a required level of Fleet availability.

Design and Construction Time-Scales

31. FV have calculated the manhours necessary for the production of a shorter, wider hull form which show a substantial reduction from current British Shipbuilders' practice with traditional designs. The advantage ratio, which could be as high as 2 to 1, arises almost entirely from the ability to use lower grade steel. This saving in time, important as it clearly is for its own sake, reads directly across to costs (para. 21).

Main Propulsion Machinery

32. FV have proposed a wide variety of propulsion installations for the Sirius hull form. These include two heavy low speed diesels of the Pielstick PC 2 range, utilising heavy "bunker C" fuel oil which is some 40% cheaper than light diesel fuel currently used by the RN. This type of ship might be popular with overseas navies requiring a sturdy, serviceable OPV with a maximum speed of about 25 knots.

33. Alternatively, a variant with four lightweight high speed MTU (Motoren Turbinen Union, consortium of Mercedes, Maybach Diesels) or Pielstick diesels with between 30,000 and 40,000 total BHP would provide a lighter machinery installation giving a greater weapons payload and a top speed of about 28 knots.

34. More sophisticated navies might require a CODAG or CODOG machinery installation such as proposed by Rolls Royce for the Sirius OPV III. This arrangement provides a maximum speed of 40 knots, or more with the Rolls Royce Spey SM 1C gas turbine engine under development.

Displacement

35. As a result of the increase in beam afforded by the Sirius hull form it is possible to sustain a displacement of between two and three times that normally associated with a given length of traditional long/thin hull.

36. This means that heavier, and therefore cheaper, construction can be used whilst still retaining a margin of about 55% of standard displacement (i.e. without fuel, stores and water) for machinery, outfit, weapons, equipment etc. This compares with a 50% margin available in a traditional hull – albeit with expensive light-weight construction.

37. It is also apparent, as pointed out by Dr Garwin, that the greater displacement on a given length provides a considerable improvement in seakeeping, reducing the frequency and accelerations in roll, pitch and heave.

Resistance, Hydrodynamic Lift, Speed and Endurance

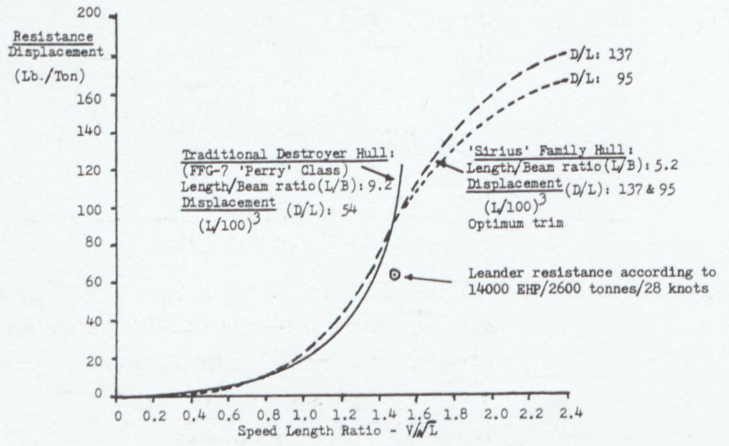
38. Resistance

The S90 design was the subject of a detailed programme of tank tests for resistance, propulsion and seakeeping undertaken with models at scales of 1/43 and 1/20 and at two UK testing tanks (BHC and NMI Ltd.) This programme was partially funded by the Department of Trade and Industry and by various interested companies (FV, British Aerospace, Dowty Fuel Systems Ltd, NEI and others); it was also agreed in advance by both MoD and DTI.

39. TGA claim that the results of this programme were not accepted by the DSAC, who relied instead on computer predictions by YARD Ltd. These demanded a large increase in the installed power proposed by FV for the S90 design, with corresponding large increases in fuel load carried and thus of weight resistance, to meet the speed and endurance requirements. We have not been able to resolve this dispute, although we understand that such tank tests are normally accepted.

40. We accept the comparison between the resistance curve of the Sirius hull form and that of a traditional full form, a US Navy Perry Class frigate, quoted in "The Procurement of a Warship". Fig. 13 from that paper is reproduced below.

FIGURE 13
Non-dimensional Comparison of Hull Resistance



41. This comparison illustrates the traditional advantage achieved by increasing length to reduce resistance for a given speed. It also shows that if constructed to the same length as the conventional form a Sirius hull of over 77% greater beam and 77% or even 150% greater displacement would still exhibit similar resistance (in terms of pounds of resistance per ton of displacement at 25 knots) and lesser specific resistance at all higher speeds up to the maximum practical speed of the traditional destroyer.

42. Taking generally agreed Perry Class resistance lines vs. the S90 we find (at 3000-ton displacement for Perry Class and S90 geometrically similar hulls) that the shorter S90 can be driven at 28 knots with effective power 25% greater than that of the conventional longer Perry Class, assuming equal propulsive coefficients. But the Sirius propulsive coefficient is considerably greater than that of, for example, the Leander class. See below under "Speed and Power".

43. The adaptability of the Sirius hull form is clearly illustrated: it is no longer necessary to increase length (thus requiring a major redesign of hull and structure) in order to achieve a 15 knot increase in speed; nor is it necessary to redesign the hull for reasonably low resistance at low speeds.

44. Where, previously it was necessary to think in terms of high and low speed hulls, it is now possible to consider a single hull which will provide an acceptable performance at both ends of the speed spectrum.

45. Speed and Power

Speed depends on more than hull resistance and power. it is also a function of propulsive efficiency, which is defined by the following fraction:

$$\frac{\text{Effective Horsepower (EHP)}}{\text{Installed Horsepower (BHP}} = \text{Propulsive coefficient}$$

46. According to "The Procurement of a Warship" already quoted, the Leander Class (at 2,600 tonnes displacement and 28 knots speed) requires an EHP of 14,000. At the same speed and displacement, the Installed Horsepower (maximum power) is 30,000 BHP. Thus:

$$\frac{\text{Effective Horsepower (14,000)}}{\text{Installed Horsepower (30,000)}} = 0.467 \text{ Propulsive coefficient}$$

The measured values of EHP and BHP in the NMI Ltd. propulsion tests of the S90 at 2600 tonnes displacement and 28 knots were:

$$\frac{\text{Effective Horsepower (27,077)}}{\text{Installed Horsepower (44,655)}} = 0.606 \text{ Propulsive coefficient}$$

47. The S90 propulsive coefficient is therefore 30% better than that of the Leander. The reason for this improvement is not understood; however, it has been demonstrated in many comparisons between tank tests and trials results for ships of the Sirius type, that the full-scale results are consistently better than tank tests. This factor has been taken into account for the NMI Ltd., S90 propulsion tests, with the result shown above.

48. Warships are only required to use their full power for a small percentage of their seagoing life since most of their operation is limited by the speed of their accompanying tankers for which only about 10% of their full power is required. At 15 knots and 3000 tonnes the propulsion of a Perry requires about 1500 EHP and that of an S90 2200 EHP. This difference will be reduced by the greater propulsive coefficient of the S90.

49. Hydrodynamic Lift

We found that sharply different opinions had been expressed in the past about whether the Sirius hull would benefit from "dynamic lift". The DSAC took the view that whatever lift might occur in small scale models would not occur, at least to a similar degree, in full scale vessels.

50. This view was evidently accepted by the Ministry of Defence and became one of the most important grounds for rejecting the Sirius concept. It appears that the DSAC relied, in forming their view, on computer predictions which took no account of the hull form in question, and consequently held that the effect of the lift on a full-scale vessel would be less (or much less) than that shown in tank tests of a small scale geometrically similar (geosim) model.

51. This has now been established to be quite untrue, and accepted as such by those who advised the DSAC, in correspondence (which we have seen) with Dr Garwin. So important is this single issue to the major military capability factors of speed and endurance that we attach a paper about hydrodynamic lift at Appendix 5.

52. Endurance

The greater usable internal space for machinery and payload available, within a given displacement, in the Sirius hull form enables increased fuel storage (and thus endurance) to be provided. This advantage is multiplied by the necessary fuel trimming system, which is most effective at heavier displacements and with large loads of fuel.

53. Indeed the addition of such a system (which would be relatively simple and inexpensive to install), so far from being a disadvantage as held by the DSAC, could confer actual advantages by enabling fuel to be constantly transferred so as to maintain the optimum hull attitude, and thus conserve fuel; and as a useful by-product would positively enhance damage control measures.

Stability

54. General

This quality is clearly crucial to all the elements of the military capability of a warship. It is probably the most controversial matter we have examined because professional technical opinions about it vary widely. We have seen the film and measured results of side-by-side sea trials of 1/10 scale models of Sirius and Leander, and have examined the results of tank tests at NMI of smaller Sirius models. We refer to these results below. We prefer the advice which we have been given that these trials read across accurately enough to full scale, to contrary advice, based upon some computer predictions, which we have seen.

55. Stability in Pitch

It is a traditional tenet of warship design that increasing length not only reduces resistance, but improves sea-keeping for a given displacement. However, full scale tests with a 165 ft. Sirius-type vessel (Osprey) have shown a reduction in pitching compared with the behaviour of traditional designs of the same length.

56. In order to estimate how the Sirius S90 would perform by comparison with a longer, thinner hull of the same displacement, comparative model tests were undertaken in head seas in the NMI Ltd. testing tank and in the open sea using 1/10 scale models of the Leander and S90.

57. These tests show that the S90, despite being some 30% shorter and of somewhat lighter displacement, was able to proceed with lower accelerations and with much less incidence of slamming and bow immersion than was measured with the Leander at the same speed and sea condition.

58. Stability in Roll

The DSAC's comments on S90 roll behaviour depend upon their assumption of a metacentric height ("GM") of 5 metres. This value only applied when the design was in the rudimentary state presented to the Hull Committee in March 1983. The results of such a high GM as 5 metres in the S90 would, as stated by the DSAC, be a small roll angle, short roll period and high lateral accelerations.

59. During subsequent refinement of the S90 design particular attention was paid to arrangement of the structure and vertical distribution of weight to reduce the GM to a smaller value. The final GM as calculated by FV for the design proposed to MOD was 3.59 metres. This was used by BHC in their ballasting and trimming of the S90 1/10 scale model for the comparative seakeeping tests with the Leander. The comparative roll characteristics used by BHC for these tests, at full scale, were as follows:

	S90	LEANDER
Metacentric height (GM)	3.59m	0.84m
Natural roll period (Ts)	8.04 secs	9.30 secs

60. At sea, in the variety of conditions tested, the average roll period of the S90 was between 8 and 9 seconds; whilst that of the Leander was between 9 and 10 seconds. This roll period for the Leander has been confirmed by measurement of a full scale ship in North Atlantic conditions. In the same 1/10 scale model, sea keeping tests showed the roll angles of the Leander were consistently greater than those measured for the S90; frequently the ship "lay over" to an angle of up to 20 degrees for extended periods of time and adopted a permanent list, in high wind forces, of about 10 degrees.

61. Stability in Yaw

Even at the lowest speeds (5 knots), the recorded yaw angles of the Leander were consistently higher than those of the S90, sometimes as much as three times the S90 value. These heavy yaw angles, particularly in following seas, adversely affected the roll behaviour in the Leander, on occasions initiating the onset of broaching and/or 'pooping'.

62. Static and Dynamic Stability

Criticisms in the DSAC report of the Sirius S90 on these grounds were, we understand, based on a preliminary design which was never formally put forward. The Sirius design as proposed for the Type 23 has been shown by FV to answer all requirements, with a large margin of reserve stability. We have not attempted to assess the possible effect of the relatively high profile of the Sirius design on its stability at speed in a cross wind, and this needs to be done. However the 1/10th scale model tests showed that, in an average cross wind speed of 63 knots, the S90 heeled much less than the Leander at 25 knots.

63. Damaged Stability

The Sirius S90 as proposed for the Type 23 satisfied the requirements laid down in the Naval Staff Requirement. FV have provided full damaged stability calculations which show that adequate stability is maintained with two compartments flooded (as required for the S90 validation programme), but that this would still apply if the ship was sub-divided as a three-compartment-standard ship.

64. Stability for Helicopter Operations

The BHC comparison of quiescent periods (the periods when the deck motion is within the operating "window" of a helicopter for landing and takeoff) shows clearly that the S90 is a more stable platform with shorter times between quiescent periods than is generally the case with the Leander.

Radiated and Hull Noise

65. Radiated Noise

Significant Radiated Noise is the product of the sound of a ship's machinery and systems being transmitted into the water by the hull. This can only be reduced by silencing the machinery etc, in question, reducing the vibrations which it transmits in the critical waveband which interferes with, or impinges upon, the ship's sonar or that of the searching enemy. These transmissions are reduced either by expensive insulation of machinery and systems by means of acoustic chambers, sound-rafts, flexible mountings etc, or by mounting such equipment as far as possible above the waterline. The selection of rotating rather than reciprocating machinery, reduction of pumps, gearing, cooling fans etc, also helps reduce the overall sound signature of the ship.

66. We have found no evidence to support the view that the noise created by the hull alone is greater for a short/fat than for a long/thin hull at the same displacement and speed. It appears, on the contrary, that in this respect the S90 is at no disadvantage over a traditional frigate provided that similar measures are taken. However, in one area, the S90 has an advantage: because of her greater reserve stability, it is possible to carry more equipment, generators, systems etc, higher in the structure thus isolating them further from the waterline.

67. Hull Noise

It has been suggested that the actual sound generated by the passage of an S90 through the water ('dynamic noise') will be greater than the longer, traditional ship travelling at a lower relative speed (i.e. "Speed/Length Ratio"). However, such hull noise is only relevant at speeds near the onset of propeller cavitation, which occurs at 12 to 15 knots. Since, most of the time, towed array speeds are around 6 knots, the difference in dynamic noise will be negligible.

Hull Form as Sonar and Towed Array Platform

68. Sonar Platform

A major priority for sonar operation is that the hull should be as silent as possible in order to reduce interference with passive sonars, and it is important that aeration around sonar (particulary in the case of a bow-mounted sonar) should be reduced to a minimum.

69. The measurement of the S90 model by NMI Ltd, at normal sonar operating speeds in irregular head seas having the same spectra as those in which a full scale Leander frigate was measured in the Western Approaches showed that the bow-emergence of the S90 was substantially less than that shown by the Leander.

70. In a significant wave-height of 6.7 metres (22 ft.) there was no measurable emergence of the S90's bow up to a speed of 18 knots. In a progressively reducing sea, the Leander recorded significant bow-emergence of 25 occurrences per hour at 12 knots, 32 per hour at 14 knots, 35 per hour at 16 knots, 60 per hour at 18 knots and 67 per hour at 20 knots. At 20 knots, the S90 recorded 8 bow-emergences per hour.

71. The above results were measured in terms of "slams", which is the only means of recording serious bow-emergence; however, the films of the S90 and Leander 1/10 scale open-sea model tests show clearly that the incidence of bow-emergence by the Leander was much greater than the S90 in all sea conditions measured. This recorded reduction in bow-emergence of the S90 must represent an advantage over the long/thin hull form in the efficiency of a bow-mounted sonar.

72. Towed Array Platform

The resistance generated by the array and its towing cable (which can together amount to 4 kilometres in length, can weigh up to 4 tons and can be hanging at a considerable angle in order to penetrate the thermocline and other thermal layers) requires considerable reserves of power and manoeuvrability on occasions, particularly in the "sprint/drift" mode. The Sirius has such reserves of power; and with her widely spaced rudders and large diameter propellers has many of the attributes considered highly desirable for this evolution.

73. Whatever is said about the complex and secretive subject of towed arrays, the current policy of using traditional destroyer hulls to tow such arrays is in contrast to the US Navy policy of using powerful towing vehicles, such as offshore supply boats, with a high bollard pull for this operation; and the Sirius design family has far more in common with them.

Upper Deck Space for Weapon Layout

74. In both the S90 and OPV III proposals by TGA the weapon layout was arranged by either BAe Dynamics Group or Consep Ltd. Neither had any difficulty in providing adequate space for the required weapons fit or the necessary arcs of fire. The critical dimension is deck area, rather than ship length; and a short/fat design provides greater area at the centre of the ship where weapons systems are most conveniently positioned. We could find no evidence to support the DSAC view that "the much reduced length of the weather deck . . . would not provide enough space for all that is required to be fitted there.", indeed we consider the reverse to be true. Moreover Professor Bishop has expressed a view that the Type 23 design may have been lengthened too much in order to accommodate deck-mounted systems.[1]

Damage Survival and Shock Resistance

75. FV have conducted all evaluations and made structural proposals for Sirius and OPV III to meet NATO standards for shock and impact damage since no RN/MOD data on these was made available to TGA.

Manning and Habitability

76. Conran and Consep Ltd have concluded on the basis of their paper[2] that the standards of accommodation for living and work are likely to be more convenient, commodious, economical and practical in a short wide ship than in a traditional long thin ship of the same displacement for the same operational requirement (Para 23 above). These advantages are clearly not only important in their own right but also reduce crew fatigue and discomfort and thus enhance operational performance, particularly in prolonged deployment.

Military Capability

77. As we have defined it in para. 8, this evolves from all the elements discussed above, and, of course, weapons performance, which is affected by many of them but is otherwise independent of hull form. In this latter connection we draw particular attention to the major improvement in the

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[1] Appendix 2
[2] Appendix 3

performance of weapon radars and other sensors which flows from the ability to mount them much higher in a Sirius hull than in a conventional design. This has been calculated to increase the detection range, and thus warning time, against a sea-skimming target flying at 650 m.p.h. by 30%. We have not attempted to assess whether the higher profile of the Sirius design has any significant effect on its radar cross section, as an offsetting disadvantage, and this needs to be done.

78. Overall operational capability of the Fleet is a function, not only of the operational capability of each individual unit, but also of the numbers of those units available. It seems that the traditional approach has reached the point of diminishing returns, since the cost of each unit has reduced Fleet numbers to the point at which the Fleet's overall capability must now be in doubt.

Conclusions

79. Using the criteria defined by the Hull Committee of the Defence Scientific Advisory Council to determine the effectiveness of a warship we believe that, certainly for ships up to destroyer size, the short/fat concept offers enough advantages over the conventional long/thin design to merit more serious consideration than it has hitherto been accorded. This appears to us to be indisputable in the crucial elements of building and maintenance costs, construction time, habitability, between-deck and weather-deck layout and stability. In operational terms the short/fat design appears to offer better sea-keeping and manoeuvring performance, with important advantages for the siting of weapons systems and their sensors and the operation of helicopters.

80. We have been unable to reach precise conclusions about some matters, such as comparative through-life costs, or the correlation of 1/10 scale model sea trials and full scale results, because the data were not available to us, but we believe it unlikely that these would vary our opinion set out above.

Recommendation

81. Because, as stated in the Introduction to this Report, the resolution of this controversy is of the very highest importance for the operational capability of the Fleet, and thus for Defence – and much Industrial – Policy as a whole, we strongly recommend that an Official Committee of Enquiry or Investigation should be put to work at once to validate or reject our conclusions and the bases for them. We further consider that because such firmly entrenched positions have been taken up by Ministry of Defence officials, British Shipbuilders and other ship designers, it is highly desirable that independent persons expert in their fields, but with no present or previous connection with those three groups, should be appointed, preferably under the Chairmanship of a learned Judge or Queen's Counsel. We believe that such a Committee, with access to both people and data which have not been available to us could, and should, be able to complete its task very quickly.

Annex A.

The Committee

Admiral of the Fleet The Lord Hill-Norton GCB. Sometime Chairman of the Defence Research Policy staff, and later Vice Chief of the Naval Staff with responsibility for the formulation and implementation of the Naval Staff Requirement for the design, performance and operational capability of all warships for the Fleet. Latterly First Sea Lord and Chief of the Naval Staff, Chief of the Defence Staff and Chairman of the Military Committee of NATO.

The Lord Strathcona and Mount Royal.
Former Minister of State for Defence.

Professor R.V. Jones CB, CBE, FRS.
Formerly a Scientific Adviser to the Ministries of Defence, Supply, Aviation and Technology.

Dr Richard L. Garwin.
IBM Fellow at the Thomas J. Watson Research Centre, New York, adjunct Professor of physics at Columbia University. Formerly for many years, and in two separate appointments, Member of the (U.S.) President's Science Advisory Committee; Chairman of its Naval Warfare Panel and its predecessor the Anti-Submarine Warfare Panel; Member (U.S.) National Academy of Engineering and of the (U.S.) National Academy of Sciences.

Appendices

1. Record of discussion;
   Garwin and Jones/Admiral Sir Lindsay Bryson
2. Record of discussion;
   Garwin and Jones/Professor Bishop
3. Accommodation – Paper by Consep Ltd., and Conran Design Group.
4. Comparative Costings-Paper by Frederikshavn Vaerft
5. Hydrodynamic Lift
6. Weapons suite installation – Paper by Consep Ltd.

APPENDIX 1

Discussion in London on 5 August 1985 between Dr. Garwin, Professor Jones and Admiral Sir Lindsay Bryson

– Note by Dr. Garwin

The talk was particularly cordial on account of his just acceding to the presidency of the Institute of Electrical Engineers, and the interest Prof. Jones and I both have in electrical and radio engineering and its applications in warfare. Admiral Bryson is an example of Naval Controller with technical background but, as expected, he explained that he had relied on recognised experts for counsel when considering the S90 as a contender for the Type 23 frigate design, although the decisions were his own. Although Professor Bishop was one of the experts cited, I had some difficulty aligning the comments Bishop made to us with the implied role of more general supporting expertise for the Type 23 in which Admiral Bryson indicated Bishop participate. Admiral Bryson commented that the short/fat ship could very well have an important role in the Royal Navy, but that it would have been a mistake to have tried to introduce it as the main line procurement for the Type 23. He volunteered that the RN really ought to build a trial ship, but that there never seemed to be the money for such an activity. He did not dissent when it was suggested that the problem was really one of priorities which made it difficult to find money for un-tried projects

I would summarise our talk with Admiral Bryson as not indicating any dissent with the approach which the Committee was taking on military capability vs. benefits, nor with the specific points made, but rather that he emphasized that the RN needed ships, and that the Type 23 could be built with confidence and was supported by expert opinion, while the S90 design fell short of meeting the military capabilities required, and was not supported by expert opinion. He expressed the view that the S90 protagonists should have sought a less demanding requirement than the Type 23 as a vehicle to demonstrate their claims (with the implication that this might well have received his support).

Note: "The above has been read by Admiral Bryson and incorporates his comments of 30th January, 1986. The Committee has no doubt that Admiral Bryson was convinced by the weight of 'expert opinion' that 'the Type 23 could be built with confidence, whilst the S90 design fell short on meeting the military capabilities required.' The detailed considerations presented in our Report reflect the degree to which analysis and testimony demonstrate that expert opinion was not properly brought to bear on this question."

APPENDIX 2

Discussion in London on 5 August 1985 among Dr. Garwin, Professor Jones and Professor Bishop

– Note by Dr. Garwin

Garwin's paper analysing and commenting upon the DSAC report on the S90 had previously been discussed and five items had been listed for discussion with Bishop:

1. Dynamic lift in large ships
2. Trim adjustment vs. speed by fuel transfer; "sprint-and drift" for effective towed array operation OR controlled winch
3. Scaling of resistance with size
4. Sea-keeping comparison – are there possible problems in interpretation of the comparative Leander-S90 self-propelled model measurements and videos of the 1/10 scale tests?
5. Damage control feasibility as influenced by metacentric height

The discussion was at first reserved, but it soon became evident that we were just scientists together, trying to understand those things on which we agreed and had no need to discuss further and to identify those on which we disagreed so that we could learn from one another.

Turning to the topics listed above, on (1) Bishop felt that dynamic lift on large ships was not normally significant. He had not made a detailed study, but he recalled making elementary calculations which had led him to doubt the importance of dynamic lift in large ships.

As for (2), Bishop noted that trim adjustment required "an additional system," but he acquiesced in considering this an item of cost to be traded against the benefits. He accepted that this might include improved damage control which could be made available from such a system. Bishop raised the question of "noise generation from a large surface in the sea" and wondered about the noise emission of the propulsion unit proposed for the S90 and its effects on a towed array. He had not considered the possibility of using a controlled winch with a towed array. Where (3) is concerned, Bishop pointed out that there is a large literature on the subject of displacement ship resistance as a function of size. It is not a speciality of his own but the subject is very well documented and could readily be followed by practitioners. His own estimates of the calm-water resistance of S90 appeared to him to require an unexpectedly large installed power.

It was on (4) and (5) that Bishop expressed most interest. He emphasized several times that fairly soon computation should replace tank and model tests, though he agreed that the time was not yet. (He felt that, nationally, research should be directed much more towards supplanting tank testing, since model tests are so expensive and introduce real problems of interpretation.) The model tests of the S90 had raised questions of Froude number which had not been answered to his own satisfaction. Bishop commented that many ships were lost without trace or explanation and suggested (as in his publication "The Safety of Ships – What's Wrong?") the massive hull cracking in some and dynamic instability in others were the most likely explanation. He forsaw no problems of hull strength with the S90. So far as hull stresses induced by waves were concerned, he was particularly firm on the need for a "high natural frequency" of the hull structure and he noted approvingly that the short fat ship should have advantages over the normal frigate hull in this particular respect, all else being equal.

In this connection he wondered if the Type 23 design had been lengthened too much in order to accommodate deck-mounted systems. Turning to the problem of stability, Bishop cited preliminary work by the Brunel University Group as indicating that ships (like trawlers) with deep transoms, at high speed in a following sea, were particularly at risk if coincidence of resonance and dynamic instability could occur. Without analysis it was difficult to say if there were implications for a choice between S90 and long thin ships. He urged that this is a serious point that requires careful consideration if the S90 design is to be adopted. Here, the balance of advantage clearly lies with the Type 23.

Finally, Professor Bishop raised a matter which he said was beginning to worry him, namely the process of procurement of naval ships and, in particular that of design. he noted that:

(a) naval hulls are essentially "of high performance";
(b) since the hull accounts for a relatively small part of a warship's cost, there is a real danger that too little attention will be paid to the various aspects of its dynamics;
(c) work on dynamic stability, hydroelacsticity, and indeed in ship dynamics in general, could not be handled adequately by any existing design team known to him;
(d) the design staff in Bath was (he felt) now becoming too small.

He felt that, such is the expense of a modern warship, it is false economy to reduce the quality and size of those teams engaged on design to the extent that was becoming apparent. He is firm about the inadequacy of the present system.

NOTE: The above has been revised and approved by Professor Bishop who has added the comment "there is an urgent need to prevent fragmentation of Britain's limited resources and, for this reason the Type 23/S90 controversy is a form of technological folly."

Garwin's comment of 21 March, 1986: As regards the presence of dynamic lift in full-size ships, Professor Bishop's "elementary calculation" appears to have been similar to my own (presented in Appendix 5 of this report). With lift proportional to hull area, to speed squared, and to a lift coefficient C, such estimates would indeed conclude that lift is as important relative to displacement (ship buoyancy) in full-size ships as in the scale-model tests.

Nevertheless, Professor Bishop does not regard himself as expert in this field and is unwilling to draw this conclusion from such analyses. In any case, he seems to judge that no one now maintains that a "square-cube" law prevents dynamic lift from being as important in large ships as in small ships or models. Professor Bishop should not be regarded as taking a position either for or against this proposition.

APPENDIX 3

Accommodation Study – Frigate
Paper by Consep Ltd. & Conran Design Group

A major criticism, often heard, in comparing RN ships with (say) their Russian counterparts is the apparent dearth of weapons in the RN vessels compared with the Russian ships which "simply bristle with weapons". A significant factor contributing to this apparent imbalance is the high accommodation standard (almost mandatory) to which the RN ships are designed. The Russian sailors, it is believed, are made to put up with very inferior accommodation in order to achieve the increased fighting capability.

The wide-beam hull form of the Sirius design allows the high standard of accommodation to be achieved with no depletion of the fighting capability. Indeed, the standard of accommodation could well be considerably higher than the current requirements without reducing in any way the weapon and other essential services. This benefit can be derived merely from the extra space which becomes available, but with modern methods of space utilisation and modern materials (fire resistant, non smoke-generating etc.,) an even higher standard becomes possible. This could have been achieved in the Sirius design for OPV 3.

The following comparison is based upon information extracted from deck plans for both Leander class frigate and the Thornycroft Giles and Associates S90 design.

The overall dimensions of the short/fat hull of S90 allows far greater space per crew member which is translated into better crew quarters for all classes of sailor, compared with the Long Thin Hull of the Leander class frigate. The total area available for officers and ratings is 1304 sq. mtrs. for Sirius and 776 sq. mtrs. for Leander.

A further benefit from the additional space within the short/fat hull is the ability for more effective space planning and grouping of crew quarters. This is particularly noticeable in the location of Junior Rating quarters – in the Leander all Junior Rating messes are situated on number 2 deck whilst the toilet and washroom facilities are positioned on the deck above. We note also that in Leander mess 3EA a hoist is required through the deck in order to access the Seawolf magazine below. The space planning appears to make no provision for a Junior Rating recreation space. In the S90 hull, the Junior Ratings are provided with washroom and heads in adjacent space to the sleeping quarters on number 3 deck, and the recreation area is also on number 3 deck.

The Senior Rating space is widely spread across number 1 deck in the Leander – sleeping areas appear to be fitted randomly into whatever space is available between the operations areas, whereas S90 on number 2 deck is designed to place washroom and toilet facilities in a grouping with the sleeping areas. The S90 will allow the lower grade of Senior Ratings to be accommodated 2/4 per mess area with the Chief Petty Officers at 1 per cabin with own washroom facilities.

Similarly, the cabin area for the Officers is improved with the additional space in the S90 Hull – all Officers are accommodated 1 per cabin with own toilet and washroom facilities, two individual cabins are held spare on number 01 deck.

The form of the hull and the layout of the living accommodation in the Leander demands a high number of hatch down/companionways for space to be readily accessed between different decks along the single corridor construction. In comparison the S90 Hull has more central positioning of the companion ways within its 2 corridor design, which allows greater opportunity for symmetry.

All area values expressing Sq. Mtrs.

Space available by deck	**Leander**	**S90**
02	6.10	86.64
01	126.62	163.01
1	319.62	24.00
2	323.68	474.38
3	–	411.29
4	–	145.02
TOTAL	776.02	1304.34

By crew rank	**Leander**	**S90**
Commanding Officer	26.56	56.94
Officers' Accommodation	84.62	130.55
Officer's Wardroom	26.39	62.16
Senior Ratings' Accommodation	136.71	286.00
Dining Room	28.99	54.28
Recreation	50.17	54.00
Junior Ratings' Accommodation	359.85	494.41
Dining Room	44.83	80.10
Recreation	–	60.90
Sick Bay	17.90	25.00
TOTAL	776.02	1304.34

APPENDIX 4

Comparative Costings – Paper by FV

Due to the fact that very little detailed information on weapons systems etc. was available to FV or the S90 'Club' concerning the weapons and electronic systems required it was extremely difficult for FV to give more than a simple budgetary indication of cost in June 1983.

Subsequently however, YARD Ltd. were invited to prepare for MOD their estimate of the Unit Production Cost (UPC) of the S90 as proposed by TGA and the S90 'Club' for the Type 23.

The assessment by YARD Ltd. was classified 'Secret' and, to the best of our knowledge, it has never been declassified. However, it is possible to state that YARD considered that the weapons package proposed by TGA for the S90 was much more capable – some 60% more costly in terms of actual hardware – than required by the Type 23. Since YARD Ltd. had previously been invited to prepare an alternative proposal for the Type 23 they were fully acquainted with all details of the required weapons package.

FV were security-cleared to receive a copy of the YARD assessment of the S90 and they have recently prepared a costing for construction of the S90 in the UK equipped with the proposed Type 23 weapons and electronics package. These costings are based on exactly the same parameters as those used by YARD Ltd., taking account of the cheaper and less elaborate weapons package and generally employing the estimates of productivity and labour rates recommended by YARD for UK construction.

Allowance has been made in this costing for fitting of the combined diesel-electric and gas turbine propulsion system required for the Type 23; and for the fact that some of the electrical content in the fitting out of the ship would be associated with the 'silent' propulsion package.

Although the figures given reflect current UK management and shipbuilding practices, *which are not necessarily as efficient or economical as those practised by FV*, FV are satisfied that these figures represent an accurate interpretation of the YARD Ltd. estimates prepared for MOD in 1983.

Unfortunately, since all the information in the YARD assessment is classified a detailed comparison between the two costings can only be made by those possessing the necessary security clearance. The detailed S90 costing calculated by FV on the basis of the estimates of YARD Ltd. for construction of the S90 in a current UK yard is as follows:

1. **Hull and Machinery** (Stage 1)

	Cost–£ (May 1983)
MATERIALS	
Steel Hull	595,000
Outfit	4,012,800
Machinery	12,000,000
Electrical	1,900,000
LABOUR	
Steelwork	2,190,000
Outfit	1,662,500
Machinery	2,250,000
Electrical	1,026,000
NET BUILDING COST	25,636,300
Security	22,000
Staff Cost (10% of net labour cost)	712,900
Contingency (10% of net building cost)	2,563,600
TOTAL COST	28,934,800
Nominal Profit	2,893,500
ESTIMATED COST OF STAGE 1	31,828,300

2. **Weapons and Electronics Installation** (Stage 2)

		£ (1983)
MATERIALS		
Weapons and Electronic Equipment		28,000,000
Electric Cables		833,000
VCS Units		167,000
Internal Communications		259,700
Misc. electric materials		416,700
Outfit (Consoles, seatings, paint, damage repair etc)		416,700
LABOUR (at £8.75 per man/hour)		
Steelwork services	123,000 m.hrs.	1,076,200
Outfit services	210,000 m.hrs.	1,837,500
Machinery	46,000 m.hrs.	400,000
Electrical (incl. 20% CODLAG)	400,000 m.hrs.	3,500,000
Security	80,000 m.hrs.	700,000
Cleaning	120,000 m.hrs.	1,050,000
DOCKYARD COSTS		
Berthage, dues etc, 30 months		100,000
Dry docking		15,000
Elect, air etc.		25,000
Tests and trials		100,000
NET COST OF WEAPONS INSTALLATION & TESTS		38,896,800
Staff Cost (5% excl. weapons)		544,800
Contingency (5% excl weapons)		544,800
TOTAL COST		39,986,400
Nominal Profit (5% of Total Cost)		1,999,300
ESTIMATED COST OF STAGE 2		41,985,700
ESTIMATED COST OF STAGE 1		31,828,300

3. **Unit Production Cost (UPC) of Completed Vessel** £73,814,000

4. **Overall Cost Breakdown**

	Total Cost–£ million	Percentage of UPC
Hull Structure	3.2	4
Machinery	18.3	25
Outfit	11.5	16
Electrical Outfit	8.8	12
Weapons	32.0	43
	£73.8 million	100 percent

APPENDIX 5

The Effects of Hydrodynamic Lift

1. The full scale Osprey ships have been shown to outperform the tank-test predictions of the speed they might achieve for a given power output. Thornycroft, Giles Ltd have suggested that this better-than-expected performance may arise, in part, from the effects of hydrodynamic lift resulting from high pressure induced under the hull by its unusual form.

2. The question of hydrodynamic lift is of the first importance in evaluating the Sirius hull form. Since that form is shorter in length and broader in beam than the conventional hulls which have become traditional in warship design, it offers considerably more resistance to the water – and hence requires more power and more fuel – than a conventional hull. However, if hydrodynamic lift reduces this resistance, the power and fuel requirements will not be as high as predictions for conventional hull-forms suggest. In addition, since hydrodynamic lift increases as the square of the speed, the presence of lift would be particularly helpful in allowing a Sirius hull-form to achieve greater speeds than a conventional vessel.

3. One method of establishing the presence of hydrodynamic lift in a testing tank is to tow the model from a point known as the 'towpoint' – the point at which the thrust-line of the propeller shafts and the transverse plane containing the centre of gravity coincide – and to measure the rise or fall of the towpoint.

4. We understand that the BHC and NMI tanks, in testing the Sirius hull-form on behalf of Thornycroft, Giles Ltd, towed the models from the correct point and found a degree of 'tow-point rise' at speeds lower than might be expected for conventional hulls. This supports the designers' claim that hydrodynamic lift may be an important factor in overcoming the greater resistance of a 'short/fat' hull, even at lower speeds.

5. It appears that the DSAC, in evaluating the Thornycroft, Giles design, placed reliance on a series of computer predictions which took no account whatever of the designers' suggestion that hydrodynamic lift might be present. Such predictions cannot be applied to a hull-form which is affected by hydrodynamic lift, because, for example, if applied to the 50 metre Osprey hull-form now successfully in service, they would show that the vessel was quite unable to achieve the speeds which it has successfully achieved in practice. In seeking the reasons for this reliance on computer predictions which do not take account of the hull form in question we have discovered, first, that in its own tank at Haslar the Navy does not usually measure hydrodynamic lift, whether by tow point rise or by pressure-sensors, and that it does not, generally, tow its models in the same way as BHC or NMI, who measure towpoint rise as a matter of course.

6. Secondly, we have found that the 'official source' at the time of the DSAC Report which rejected the Thornycroft, Giles design, made an elementary but not obvious error, exposed by Dr Garwin in correspondence since, which led the MOD (N) and others who depended upon his advice to believe that whatever hydrodynamic lift might occur in small-scale models would not occur to a similar degree in full-size vessels.

7. The essence of the 'official' error is sufficiently simple to be described here. On 13 April, 1981, in a letter to Mr David Giles, an MOD official wrote: 'such dynamic advantage is confined to quite small craft and is lost at OSPREY displacements – not surprisingly because displacement varies as the cube of the dimension and dynamic lift as the square.' This is a far from complete statement of the truth. Lift varies not only as the square of the length but also as the square of the speed.

8. On 22nd September, 1981, after four exchanges of letter with Dr Garwin, the same 'official' wrote: 'Like other dynamic forces the lift coefficient will be the same for geosims at the same Froude number'. This was in effect, a reversal of the official's original position, though he did not explicitly admit that he had been wrong, and his recantation was couched in such unclear terms that the Royal Navy appears still to support his original error.

9. The Froude number of vessel length L running at velocity V under gravity g is $V/\sqrt{gL}$, a variable which measures the influence of gravity on the vessel passing through the water. To make a realistic assessement of the likely performance of a full-scale vessel based on the measured performance of 1/x-scale model, the model is run in the tank at a speed such that the Froude numbers of the model and of the full-scale vessel are the same.

10. The length of a 1/x-scale model of vessel of length L is L/x: hence, to make the Froude number of the model, Fm, equal to that of the vessel, Fv, the model is run at a velocity of $V/\sqrt{x}$, which ensures that

$$Fm = \frac{V/\sqrt{x}}{\sqrt{gL/x}} = Fv = \frac{V}{\sqrt{gL}}$$

For example, where $x = 25$, a 1/25 scale model will be run in the tank at $V/\sqrt{x} = V/5$, or 1/5 of speed of the full-scale vessel.

11. The 'Official' Naval Architect had overlooked either that models in tank tests are, for the above reason, run at a slower speed than their full-scale geosims (geometrically similar vessels); or that hydrodynamic lift varies not only in proportion to the square of the length but also in proportion to the square of the velocity; or both.

12. Thus the official concerned had assumed that, since lift varies as the square of the length while displacement varies as the cube (this is an example of what is known as the 'square-cube law'), the ratio of lift to displacement – and hence the effect of lift upon the hull – would be less for the full-scale vessel than it had been for the model, *while in reality the ratio of lift to displacement – and hence the effect of lift, will be the same for the full-scale vessel as it was for the model.*[1] This result is precisely what might be expected in geosims at the same Froude number, since hydrodynamic lift is a force which acts in direct opposition to the force of gravity.

13. It is unfortunate, to say the least, that as a result of this error in fact the DSAC should have wrongly been advised, and concluded, that "a vessel of the size of the S90 will not gain any benefit from hydrodynamic lift at the operational speeds that are required".

14. It appears to us that this error has led to a widespread belief throughout the field of (RN) naval ship design that lift as measured in a tank-test will not be achieved to the same degree in a full-scale geosim at the same Froude number. This belief seems to be reflected in Admiral Sir Lindsay Bryson's paper 'The Procurement of a Warship', and in some of the comments upon it, as it is likewise reflected in the DSAC report.

15. Although it is now clear that it was wrong to reject the possibility of hydrodynamic lift on the stated grounds, it has not yet been established beyond doubt whether or to what degree hydrodynamic lift is present in the Sirius designs. However, the evidence from BHC and Frederikshavn Vaerft, taken with the Osprey's out-performance of tank-test and computer predictions, leads us to believe that, as a matter of urgency, a thorough programme of tests to determine whether lift is indeed present and, if so, what advantages flow from it, should be conducted.

[1] The formulae from which the calculations which demonstrate this fact are made are not in dispute, but are difficult to reproduce in this report, as it is printed.

APPENDIX 6

Weapon Suite Installation in a Sirius OPV III

Paper by Consep Ltd.

1. Introduction

The selection of a warship's weapons suite to meet a stated operational requirement is a compromise/trade-off between three conflicting factors:–

Operational performance, costs and ship-fitting constraints.

In some classes of ship – e.g. the early capital Type 42's, the constraints imposed by the hull design were so restricting that the overall operational performance of the vessels (not to mention the possibility of improvements) suffered tremendously. It is likely that the constraints also contributed to an escalation of the build costs because of the problems that arose in trying to "fit it all in" the space available (e.g. the problems of the "deep beam" in fitting the computer outfit).

2. The Wide Beamed Ship

From the weapons point of view, the advantages of the wide-beamed ship are so overwhelming that, by themselves, they constitute a very powerful argument in favour of this type of hull form. The advantages may be grouped under four headings:–

a) The larger clear decks available allow a much wider selection of weapons to be sited on the upper decks, with much better arcs of fire and a correspondingly enhanced operational performance.

b) The larger spaces between decks allow a much more easily achieved optimum layout of equipment in such vital spaces as the Operations Room, the various weapon control rooms, magazines (particularly torpedo magazines with Magazine Launched Torpedo Tubes) etc. As well as ensuring enhanced operational performance the maintenance and upkeep tasks are made considerably easier, which could contribute to a reduction in complement.

c) The increased stability margins allow considerably greater weights to be placed higher in the ship, giving increased range performance for such equipments as radars, communications etc. over identical equipments sited lower down. Again, an enhanced operational performance and better maintenance layouts.

d) The increased "sea-kindliness" with much reduced ship movements places far fewer limitations on the operational performance of the weapons (and would certainly make them easier and cheaper to develop ab initio).

3. The Sirius OPV III Design – Wide Beam

When it came to defining the weapon suite for the Sirius OPV III, it quickly became apparent that because of the advantages outlined above, the ship-fitting constraints had virtually disappeared. We were faced with the very unusual situation for weapons system engineers of being able to make trade-offs between operational performance and cost without having to worry about whether the weapons chosen could be squeezed into the space available. In the event, the weapons chosen gave a very powerful performance for a moderate cost. Other weapons/combinations giving a more sophisticated operational performance could easily have been accommodated if cost had not been a major consideration.

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THE HILL-NORTON COMMITTEE
HULL FORMS FOR WARSHIPS

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IMPORTANT: This information is provided to you under a strict embargo of 12 noon on Thursday May 29, 1986.

The report of a committee chaired by Admiral of the Fleet Lord Hill-Norton is expected to be highly critical of the cavalier dismissal by Ministry of Defence technical experts of claims by the designers of a new breed of warship.

The Committee of eminent international Naval and Defence experts is an unofficial body formed after a long standing public controversy over the rival merits of a short/fat hull and the conventional long/thin design traditionally favoured by the Royal Corps of Naval Constructors.

The Report was submitted to the Prime Minister at the end of April, who has accepted the recommendation of the Committee that an official inquiry should be commissioned to validate or reject their conclusions. It will be conducted by a professional expert of recognised impartiality.

The short/fat (Sirius S.90) designers, Thornycroft Giles and Associates, claimed that their vessel would be cheaper to build and maintain, more stable and faster, with more powerful weapons systems and better crew accommodation than conventional designs.

These claims were rejected by the Naval Architects at Bath for reasons which the Committee found to be sometimes wrong in fact and in other instances not well founded.

Copies of the report will be available from 1115 am on Thursday May 29 at The Boswell Room, London International Press Centre, Shoe Lane EC4, prior to a News Conference to be held by Lord Hill-Norton and his Committee at 1200.

The Report will otherwise be available only by post from Broadcast Management Services.

Lord Hill-Norton will be available for Radio and Television interviews immediately after the News Conference.

THE HILL-NORTON COMMITTEE

Admiral of the Fleet The Lord Hill-Norton G.C.B., (Chairman). Sometime Chairman of the Defence Research Policy staff, and later Vice Chief of the Naval Staff with responsibility for the formulation and implementation of the Naval Staff Requirement for the design, performance and operational capability of all warships for the Fleet. Latterly First Sea Lord and Chief of the Naval Staff. Chief of the Defence Staff and Chairman of the Military Committee of NATO.

The Lord Strathcona and Mount Royal. Former Minister of State for Defence.

Professor R.V.Jones, C.B., C.B.E., F.R.S. Formerly a Scientific Adviser to the Ministries of Defence, Supply, Aviation and Technology.

Dr. Richard L.Garwin. IBM Fellow at the Thomas J.Watson Research Centre, New York, adjunct Professor of physics at Columbia University. Formerly for many years and in two separate appointments, Member of the (U.S.) President's Science Advisory Committee; Chairman of its Naval Warfare Panel and its predecessor the Anti-Submarine Warfare Panel; Member (U.S.) National Academy of Engineering and of the (U.S.) National Academy of Sciences.